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A PLAN FOR IMPROVED SHORT-RANGE AVIATION WEATHER FORECASTS.(U)
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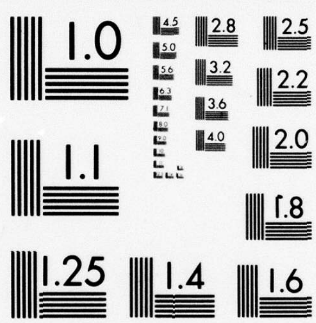

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A PLAN FOR IMPROVED SHORT-RANGE AVIATION WEATHER FORECASTS

(6)

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16. Abstract

The aviation weather needs for terminal and enroute aircraft operations are presented; the nature and interrelationships of the National Weather Service with the military and civilian weather services are described; and methods of improving aviation weather forecasts are discussed.

Recommendations are made for the overall improvement of the short-range (0-4 hours) forecast system and for improved forecasts of specific aviation weather phenomena.

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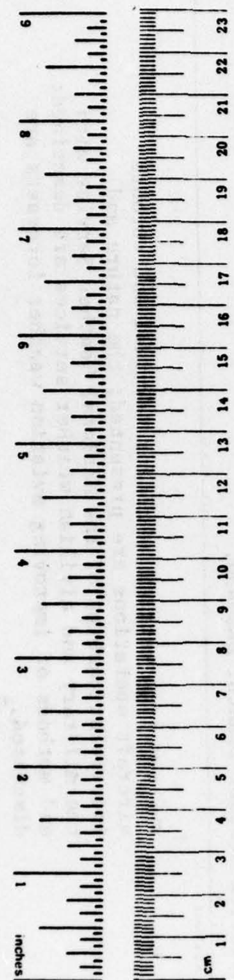
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

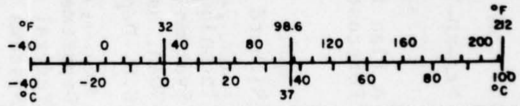
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Preface

This report was first completed in 1974. Because of the delay in its publication, considerable revision was necessary to bring it up to date. The author gratefully acknowledges the assistance of Dr. M. A. Alaka and E. M. Gross (NWS), and Arthur Hilsenrod (FAA) in making the necessary changes.

REPORTS RELEASED UNDER
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	REPORT NO.	
1.	FAA-RD-70-22	Development of Base Techniques for Ceiling and Visibility Prediction
2.	FAA-RD-70-26	Single Station Prediction of Ceiling and Visibility
3.	FAA-RD-70-37	Predicting Ceiling and Visibility with Boolean Predictors
4.	FAA-RD-70-43	Regression Estimation of Surface Winds
5.	FAA-RD-71-102	Developing Techniques for Automated Forecasting of Clear Air Turbulence
6.	FAA-RD-73-13	Automatic Probability Forecasts of Ceiling and Visibility Based on Single Station Data
7.	FAA-RD-73-14	An Application of Model Output Statistics to Prediction of Ceiling and Visibility
8.	FAA-RD-73-117	Objective Technique for Forecasting Thunderstorms and Severe Weather
9.	FAA-RD-74-86	Automated Ceiling and Visibility Forecasts - An Evaluation on an Operational Test
10.	FAA-RD-74-100	A Subsynoptic Update Model and Forecast System with Application to Aviation Weather

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LIST OF ACRONYMS

AFGL	Air Force Geophysical Laboratories
AFOS	Automation of Field Operations and Services
ARTCC	Air Route Traffic Control Center
ARF	Aviation Route Forecasts
AWFC	Aviation Weather Forecast Branch
AWP	Aviation Weather Processor
AWS	Air Weather Service
CAT	Clear Air Turbulence
CPF	Central Processing Facility
CWEF	Center Weather Facilities
FA	Area Forecast
FAA	Federal Aviation Administration
FAR	Federal Air Regulation
FSS	Flight Service Station
FT	Terminal Forecast
GOES	Geostationary Operational Environmental Satellite
GWC	Global Weather Central
LFM	Limited-Area Fine Mesh Model
MOS	Model Output Statistics
NAFEC	National Aviation Facilities Experimental Center
NAS	National Airspace System
NASA	National Aeronautical and Space Administration
NESS	National Environmental Satellite Service
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
OM&O	Office of Meteorology & Oceanography
OTS	Office of Technical Services
PATWAS	Pilot's Automatic Telephone Weather Answering Service
PE	Primitive Equation
PIREP	Pilot Report
PSBT	Pilot Self-Briefing Terminal
RAREP	Radar Report
RASS	Radio Acoustic Sounding System
RVR	Runway Visual Range
RVV	Runway Visibility
SEV	Sensor Equivalent Visibility
SDO	Systems Development Office
SIGRAD	Significant Radar Echoes
SINGSTAS	Single-Station Statistics
SLP	Sea-Level Pressure
SMS	Synchronous Meteorological Satellite
SRDS	Systems Research & Development Service
SUM	Subsynoptic Update Model
SVR	Slant Visual Range
TAO	Testbed for Automated Observations
TDL	Techniques Development Laboratory

T&EL	Test and Evaluation Laboratory
TSC	Transportation Systems Center
TWEB	Transcribed Weather Broadcast
USAF	United States Air Force
VAS	Vortex Avoidance System
WSFO	Weather Service Forecast Office
WSO	Weather Service Office

1.0 Introduction

To clarify approaches for improving short-range aviation weather forecasts, the following topics are discussed:

a. The purpose of this report and the plan for improved forecasts.
b. The present short-range aviation weather forecast system.
c. The requirements of a new system.

1.1 Purpose

This document describes a plan for the development of a new system which will provide improved aviation weather forecasts and warnings for the period of 0 to 4 hours after issuance. As used in this document, the term "short-range" will always bear this definition. This document will:

a. Describe the developmental effort required to provide improved short-range forecasts.

b. Outline a plan of action to accomplish those objectives which appear readily attainable.

c. Propose the means of achieving national agreement on the plan by the affected agencies.

d. Discuss procedures for accomplishing the transition to a new short-range forecast system with minimum interference with present operations.

This report will not provide a schedule for the proposed forecast development efforts nor the costs involved with those efforts. These, as well as major portions of this report, will be included in a formal engineering and development program plan prepared by the Federal Aviation Administration (FAA).

1.2 Short-Range Aviation Weather Requirements

Accurate and timely weather forecasts are necessary to decide the courses of action that assure safe, comfortable, economical and expeditious aircraft operations. In 1976, there were 64 million aircraft operations* requiring weather information. In 1985, the number of expected operations will be 93 million. While the number of aircraft operations continues to increase, the duration of individual flights has been decreasing. Recently compiled statistics show that 80% of flights have a duration of less than two hours and 95% last less than four hours. Thus, there will

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*An aircraft operation is defined as a landing or take off by air carrier, general aviation, and military aircraft from airports having FAA towers. Thus, it does not include some air carrier and a large number of general aviation aircraft operated from airports not having FAA control towers.

be a growing number of aircraft operations which require accurate short-range aviation weather forecasts for periods of four hours or less in order to allow rapid decision making.

Basically, there are two distinct groups of short-range aviation weather users--pilots and air traffic controllers. The latter are responsible for: (1) enroute traffic control at facilities like FAA Air Route Traffic Control Centers (ARTCC), and (2) traffic control in terminal areas. With a few exceptions, the needs of pilots and controllers, in terms of specific aviation weather phenomena, are identical. However, while the controller is concerned only about the relationship between weather conditions and the safety of aircraft operations, the pilot is also concerned about the economic consequences of the weather affecting his flight. Air line dispatchers might be considered to constitute a third group but their needs comprise those of the two basic groups. Fixed-base operators and FAA Flight Service Station (FSS) Specialists serve the pilots by providing them with the information required to make their flights safe and expeditious.

Within the two basic groups, a further breakdown of short-range weather requirements can be made with respect to the two segments of each flight operation, terminal and enroute. Table 1.1 lists the specific terminal and enroute weather phenomena for which observations and short-range forecasts and warnings are required for aviation operations.

1.2.1 Terminal Weather Phenomena

Cloud and visibility information is needed to determine what kinds of aviation operations can be conducted at a terminal with respect to Federal Air Regulations (FAR's) and the limits of a given pilot/aircraft combination. With respect to clouds, this information is needed in terms of the height above the ground of the base of a cloud layer, and the fraction of the celestial dome covered by that layer, for each cloud layer in the terminal operations zone. Most commonly, specific values are observed (measured) and forecast with respect only to the base heights and layer amounts as seen from the ground in the immediate vicinity of the terminal runway(s). This form of cloud information is used to determine the existence of a "ceiling" -- the lowest height above the ground at which more than half of the celestial dome is covered by clouds -- which in turn dictates permissible aviation operations. However, cloud height and amount information is also needed in the approach and holding zones of a terminal.

Visibility information pertains to: (1) the maximum forward distance a pilot can see when the aircraft is either on the runway or making its final approach. In the latter case, this form of information is called slant visual range (SVR) for which there is currently no operational system. For the former case, visibility is expressed as either runway visibility (RVV) or runway visual range (RVR); (2) the greatest horizontal distance at which known objects can be seen and identified over half or

Table 1.1. Weather phenomena for which observations and/or short-range forecasts and warnings are required for aircraft operations, arranged by flight segment.

Terminal Weather Phenomena	Enroute Weather Phenomena
Cloud Heights and Amounts	Cloud Layers (Bases and Tops)
Visibility and Obstruction to Vision	Winds
Runway Visual Range	In-Flight Visibility
Surface Wind (including gusts)	Temperature Aloft
Low-Level Wind Shear	Turbulence
Weather Affecting Wake Vortex	Thunderstorms
Turbulence	Icing (Freezing level)
Thunderstorms	Altimeter Setting
Icing	Ozone
Significant Precipitation (freezing, snow, heavy rain, hail)	
Density Altitude	
Surface Temperature	
Altimeter Setting	

more of the horizon circle. This form is called "prevailing visibility" or "meteorological visibility" and is the way visibility is most commonly observed and forecast.

At most terminals in the U.S., prevailing visibility is used to determine permissible aviation operations, in accordance with FAR's, in a manner parallel to the way ceiling is used. However, at large commercial airports, instruments routinely measure RVR which is used to determine permissible operations. RVR measurements, together with sophisticated electronic guidance systems installed at some airports, permit operations even when conventional ceiling and prevailing visibility conditions are well below the minimums prescribed by FAR's. No operational measurements are currently made of SVR; however, research is continuing to develop a capability for its measurement.

Surface wind information is needed by the controller to determine active runway usage and corresponding traffic patterns; it is needed by the pilot for landing and takeoff considerations. Information on anticipated wind shifts is needed by the controller to prepare for active runway changes. Especially important for both groups is information concerning strong crosswinds. Such a condition can create traffic problems or curtail operations, particularly when combined with poor runway conditions caused by snow, ice, or heavy rain.

Low-level wind shear pertains to the horizontal and vertical changes in both speed and direction of the wind at low altitudes. Severe wind shears occurring below 1500 feet in the terminal area are hazardous to aircraft

during final approach and takeoff. When an aircraft is flying slightly above stall speed a major change in wind velocity can lead to a significant gain or loss of lift. Significant low-level wind shear can be associated with warm and cold fronts, low-level jet streams, thunderstorms, and other factors such as sea breezes and subsidence inversions. The FAA Engineering and Development Plan-Wind Shear (FAA, 1977) specifies the requirement to investigate solutions to terminal area wind shear hazards in three general areas: (1) through the use of ground-based equipment; (2) through the use of airborne equipment; and (3) by improving the accuracy of terminal area wind shear forecast techniques.

An aircraft in flight leaves in its wake two counter-rotating cylinders of air trailing from the wing. They are known as trailing wake vortices, and can present a severe hazard to following aircraft. With the introduction of large transport aircraft, the wake vortex problem has taken on added significance, because of the more intense vortices they create. The increasing number and diversity of aircraft continually increases the probability of a hazardous aircraft vortex encounter. Initially, the characteristics of the wake vortex are determined by factors related to the aircraft gross weight, airspeed configuration and wingspan. Subsequently, the vortex characteristics are altered and eventually dominated by interactions between the vortices and the ambient atmosphere (e.g., Hilsenrod, 1967). The wind, wind shear, turbulence, atmospheric stability, and the proximity of the ground affect the motion and decay of vortices.

Turbulence, whether of the convective or mechanical variety, can cause aircraft handling problems for pilots, which in turn has an effect on traffic control. In the case of strong convective turbulence around thunderstorms, the necessity of avoiding such regimes can result in control zone problems and perhaps suspension of operations for periods of 30 to 60 minutes or more, depending on the location of the thunderstorm(s). While thunderstorms can be detected by radar and associated turbulence areas established by inference, no measurements of turbulence, aside from direct aircraft encounters, are presently made. However, research is being conducted to develop the capability to measure turbulence directly.

Information about thunderstorms in the vicinity of terminals is required not only because of the associated turbulence, but also because of the other hazards frequently encountered around thunderstorms--lightning, hail, sudden wind shifts and shears, and heavy rain. The usual practice is to assume that likelihood of such dangers is always high enough to warrant circumnavigation which, as just mentioned, can sometimes cause serious traffic delays.

Icing is not the problem it once was for large commercial aircraft because of warm wing equipment and modern deicing gear. However, severe icing conditons, including freezing rain, should be avoided. Information about icing conditions is required for terminal operations,

especially for light aircraft and helicopter operations at low altitudes. This information, which should eventually include air temperature, liquid water content, and drop size distribution of the clouds, will be used by the pilot to determine the potential of icing on his aircraft on the basis of its characteristics, e.g., speed, shape, flight characteristics, etc. Until satisfactory and economical rotor blade deicing systems are developed for helicopters, safe operations are dependent on reliable and accurate icing forecasts. Such information is also needed by controllers to avoid holding aircraft in icing zones.

Significant precipitation is defined as any of the following: freezing rain or drizzle, snow, heavy rain, and hail. Freezing precipitation causes a multitude of problems at a terminal since runways, unhangared aircraft of all types, ground transporation, and various kinds of equipment, can become coated with ice and rendered useless. Snow, even in moderate amounts, causes problems both with ground conditions and visibility for flying conditions; heavy snow can force cessation of all terminal operations. Heavy rain can seriously restrict visibility and create runway conditions conducive to hydroplaning. Hail, mentioned above in conjunction with thunderstorms, can cause serious airfoil and engine damage/flame-out.

Pilots need information about the surface temperature and altimeter setting to calculate required runway length for takeoff operations with respect to the aircraft gross weight. Some terminals, particularly those at high elevations may not have sufficiently long runways to permit safe operations with desired or anticipated loads when high surface temperatures prevail. In such instances, temperature and altimeter setting information becomes a critical necessity. Accurate altimeter settings are also needed for landing.

1.2.2 Enroute Weather Phenomena

Enroute weather information involves fewer specific phenomena and, in general, is somewhat less demanding than its terminal counterpart with respect to the degree of sophistication required. No diminution of its importance is intended, as implied in the previous sentence, merely a comparison of relative needs. While it is true that more problems arise and a preponderance of hazards exist for terminal operations, enroute weather problems can also be serious. However, maneuverability in time and space is usually greater when enroute problems occur.

Information on cloud cover, including cloud bases and tops, is of primary importance to aviation activities. Aircraft which are not equipped for instrument flying are legally required to maintain specified vertical and horizontal clearance distances from clouds. Even when meeting the criteria for instrument flying, pilots can greatly reduce the dangers of midair collisions by avoiding clouds, and pertinent cloud layer information can be used when selecting a flight altitude.

Upper-level winds and temperatures are needed to ascertain flying time and fuel consumption requirements. Although the need is essentially one of economics and fuel conservation, miscalculations due to improper information can affect the safety of aircraft operations.

Turbulence during enroute flight operations can be caused by thunderstorms and other forms of convective activity, or can be associated with certain types of large scale atmospheric circulation features such as the jetstream and mountain waves, among others. The latter type of turbulence is commonly labeled as clear air turbulence (CAT) in spite of the fact that it is more often encountered in clouds not associated with thunderstorms. Because either type is hazardous to aircraft operations, turbulence information is primarily a safety requirement. Pilots must select flight routes and levels accordingly, and air route traffic control centers (ARTCC) should maintain cognizance of turbulence zones when rerouting aircraft. When circumnavigation is required, or when other deviations in flight plans occur as a consequence of turbulence, traffic patterns and schedules can become disrupted, which may lead to delays, traffic handling problems and subsequent economic losses. The remarks made about the detection of turbulence in the discussion of terminal weather phenomena also apply here.

With the exception of heavy rain and sudden wind shifts, the impact of thunderstorms on enroute aircraft operations is virtually the same as it is in terminal aircraft operations, and all related discussion in that section also applys here. Similarly, the statements made about the selection and changes of flight routes with respect to turbulence, in the section above, apply to thunderstorms.

Icing problems for enroute operations are far less significant than those resulting from turbulence or thunderstorms. As mentioned earlier, modern equipment has eliminated the problem for many aircraft and, armed with cloud layer and temperature information, along with the height of the freezing level, potential icing zones can usually be avoided by all aircraft. Nevertheless, information about freezing level, icing and freezing precipitation is still required by both pilots and controllers for those situations when neither of the two solutions above are applicable.

Ozone is a toxic gas formed in the atmosphere, with the highest concentrations in the lower stratosphere. At times, the outside air ingested into the aircraft will contain concentrations of ozone that will have toxic effects on the passengers. Information on the locations of ozone concentrations in the atmosphere would be useful in planning flights that will avoid potentially hazardous ozone conditions (Belmont et al., 1978).

Altimeter settings are needed for enroute operations by: (1) pilots to maintain aircraft separation and terrain clearance, and (2) controllers

to determine the lowest useable flight level at altitudes of 18,000 feet and above. Both of these needs are stipulated by an FAR for reasons of safety. Accurate measurement of altimeter settings from terminals are transmitted to pilots for use in their landing operations.

1.2.3 Criteria for Improving Aviation Weather Forecasts

An examination of short-range aviation weather needs cannot be confined solely to specific weather phenomena in terms of accurate observations and forecasts. While accuracy, defined as the degree to which an observation or forecast describes a phenomenon, is extremely important, other measures can be made of short-range weather information: timeliness, accessibility, reliability, repeatability, and acceptability.

The most accurate weather information can be worthless if it is not available to the user when it is needed. The timeliness of weather information can be measured in terms of the amount of time a user has in which to make a decision based on the content or impact of the information received; user lead time requirements may vary between a few minutes and several hours. Weather information, be it observed or forecast, must be generated and disseminated to meet those requirements.

Accessibility is a measure of the effort required to obtain needed weather information. It necessarily involves the systems and the associated procedures and degrees of difficulty in operational practice. To help meet the criterion of timeliness, minimum user effort should be required to access weather data, in combination with the most rapid means of communication available.

Reliability is defined as the level of confidence the users attribute to the fulfillment of their short-range weather needs; it essentially combines the respective measures of accuracy, timeliness and accessibility. A reliable short-range weather information system requires that the most accurate data available be provided to the users with sufficient lead time for their needs, in a manner which demands little or no effort by the users to obtain them.

Repeatability can be evaluated in different, but related, ways. To the meteorologist it means that identical input will always produce identical output. Examples would be mechanical devices for measuring various states of the atmosphere, or completely objective forecast techniques. For the users it means that at any given time the weather information they receive will always be identical, regardless of the physical location of their access point. This implies a single, multi-accessible weather information source which is uniform, consistent, and timely.

Acceptability is the final judgement that can be made by the users after it has been determined that the other measures of effectiveness, discussed above, are being satisfied. That is to say, is the information they receive understandable, complete, relevant, and useable? The ultimate goal of a short-range aviation forecast system would be to

provide weather information to all its users in a manner that completely satisfied their needs and permits optimum utilization.

1.3 The Present Short-Range Aviation Weather Forecast System

The title of this section is somewhat of a misnomer because, as such, no single "system" exists to provide for short-range forecast needs. In fact, five different sources of forecast information can be identified: the National Weather Service (NWS), the Air Weather Service (AWS) of the U.S. Air Force, the Naval Weather Service of the U.S. Navy, the weather offices and services established by a number of commercial airlines, and certain private meteorological business firms. Table 1.2 lists the five sources, their forecast products with short-range applications, and their primary users. Not all these sources are available to each user; some serve highly specialized aviation weather needs while others respond to more general demands. However, none of the five operate entirely independently, although the extent of interdependency is quite variable.

1.3.1 National Weather Service

The NWS is, by far, the largest source of forecast information. It provides directly for the needs of all civilian air traffic controllers, virtually all general aviation pilots, a significant number of commercial airline pilots, and certain military operations. Surface weather observations are made at several hundred stations operated by the NWS and the FAA. Pilot reports (PIREPS) from general aviation pilots and some commercial airline pilots are collected, summarized and disseminated. Radar reports (RAREPS) from NWS and FAA radars are collected and disseminated. These observations, PIREPS, and RAREPS serve as basic information to all aviation interests and provide a substantial portion of the input data for short-range forecasts. The NWS issues forecasts for more than 480 terminals and a variety of forecasts which provide enroute information.

Terminal Forecasts (FT's) are prepared and issued at NWS Weather Service Forecast Offices (WSFO's), which number 52 at this time (1977). A typical WSFO is responsible for issuing forecasts for 6 to 12 terminals in its area of responsibility. FT's are routinely issued three times per day* and cover the period from 0 to 24 hours after issuance time; amendments can be issued at any time and cover the balance of the original forecast period. No distinction is made in the NWS FT between the 0-4 hour portion of the forecast period and the remainder of the period out to 18 hours (a distinction is made, however, for the last 6 hours of the 24 hour period). In this respect, the short-range and longer range forecasts are combined. The required weather phenomena to be included in each FT are: cloud heights (bases) and amounts, prevailing visibility, "weather" (obstructions to vision, significant precipitation, thunderstorms), surface wind (speed and direction), strong low-level wind shear,

*Four times per day in Alaska and Hawaii.

Table 1.2. Sources of aviation weather forecast information.

Source	Forecast products with short range applications	Primary users
National Weather Service	Terminal and Area Forecasts In-Flight Advisories Winds/Temperature aloft forecasts	Air traffic controllers General aviation
USAF Air Weather Service	Terminal forecasts Computer flight plans Special USAF mission forecasts Significant weather advisories	Military air traffic controllers Military pilots
Naval Weather Service	Terminal forecasts Special Navy mission forecasts	Military air traffic controllers
Commercial airlines weather offices	Terminal forecasts Computer flight plans Significant weather advisories	Commercial airline pilots Dispatchers
Private meteorological firms	Tailored forecasts Computer flight plans	Small commercial carriers

and turbulence. The first four phenomena are described in a standard format while the next two are included as remarks at the forecaster's discretion. Also included in the remarks section can be anything the forecaster considers of importance to aviation operations. No requirements exist for forecast information about wake vortex effects, icing, surface temperature, or altimeter setting. The standard method for dissemination of the NWS FT is on long-line teletype circuits. Users can access the forecasts directly or, more commonly, through the information/briefing services of the NWS, FAA, fixed based operators, and, as appropriate, weather offices of commercial airlines.

Provisions exist in the NWS FT program for certain Weather Service Offices (WSO's) to issue "limited short-period" FT's for 0-2 hour periods. The procedure is designed to let the WSO issue amendments to cover local weather developments and quickly alert local users. This form of FT is not disseminated on long-line circuits but only over local communication channels such as electrowriter, telephone, local teletypewriter, etc. The amendment must be coordinated with and approved by the governing WSFO; the latter normally will issue a standard amended forecast for long-line distribution.

The NWS aviation forecasts which are primarily intended for enroute use are: Area Forecasts, In-Flight Advisories, route forecasts, and winds and temperatures aloft. The first two types of forecasts are issued by certain WSFO's; the third is issued at all WSFO's, the fourth type is issued by the National Meteorological Center (NMC) of the NWS.

A number of designated WSFO's issue Area Forecasts (FA's) which, in total, provide enroute weather information for the U.S. FA's are routinely issued at 12 hour intervals* and cover the period from 0 to 18 hours after issuance time in detail, followed by a 12 hour categorical outlook; amendments can be issued at any time, as needed. As with the FT, no special consideration is given to the short-range portion of the FA. Required weather phenomena in FA's are: significant layers (bases and tops) of clouds, widespread low surface visibilities, thunderstorms, significant precipitation, widespread strong surface winds, turbulence, and icing conditions including freezing levels. FA's are disseminated and accessed in the same manner as FT's.

In-Flight Advisories are the only NWS products expressly intended for short-range use. They are issued on a non-scheduled basis by the same WSFO's responsible for Area Forecasts and are used to provide enroute information about potentially hazardous weather phenomena for periods of 6 hours or less with lead times from 0 to 2 hours. Specific phenomena which require the issuance of In-Flight Advisories are: tornadoes, squall lines, embedded thunderstorms, large hail, icing and turbulence of moderate or greater intensity, and strong low-level winds. Provision has also been made for In-Flight Advisories on extensive areas of ceilings/visibilities below 1,000 ft/3 mi, respectively, and continuous moderate turbulence over mountainous terrain. These types of advisories are disseminated over long-line teletype circuits and, to a great extent, by means of ARTCC and FSS radio communication facilities.

Automated forecasts of winds and temperatures aloft over the entire U.S. are issued twice daily by the National Meteorological Center (NMC) for various levels from 3,000 to 39,000 ft above sea level.** For levels at 12,000 ft and below, the forecasts are for actual altitudes for levels of 18,000 ft or higher, the forecasts are for pressure altitudes. These forecasts which verify 6 hours after issuance time (12 hours after observed data time) can be used for short range needs. They are designed to be used for the period 0-9 hours after issuance time. All forecasts are disseminated on long-line teletype circuit and also on computer to computer links, the latter method being of use principally to some commercial airline weather offices. Amendments to winds and temperature aloft forecasts, when required, are also issued by the Aviation Weather Forecast Branch (AWFB) of NMC and by the area forecast centers.

Route forecasts are prepared by 52 WSFO's in the conterminous U.S. for about 330 established routes. They are issued routinely three times per day and are valid for the period 0-12 or 0-18 hours after issuance time (the period is determined by the time of issuance) with an additional 12-hour outlook period. Amendments, as needed, can be made at any time. Route forecasts are used in the texts for the Pilot's

* 6-h intervals in Alaska and Hawaii.

**Plans are underway to develop a program which would provide a wind and temperature forecast for any required level or location in the U.S.

Automatic Telephone Weather Answering Service (PATWAS) and the Transcribed Weather Broadcasts (TWEB). The latter is a product of the FAA and is disseminated by continuous radio transmission. Both types are used by pilots who need preflight planning information. In many cases, pilots receive no additional information prior to their flight. In addition to preparing route forecasts, selected WSFO's also prepare local vicinity (50 mile radius) forecasts for TWEB/PATWS use in large metropolitan areas to support local flight operations. Besides being available by means of radio broadcasts and telephone recordings, route forecasts can be obtained through the use of request/reply teletype circuits.

In the preceding discussion of various NWS aviation weather forecasts, it was indicated that the only product which could be considered a short-range forecast is in the In-Flight Advisory. It must be recognized that, under normal conditions, the other products only meet the criterion for only the first four hours of the forecast period. Beyond that, they are longer-range forecasts with normal associated decay in accuracy which affects their use. Exceptions occur when forecasts are amended, for then the first four hours of the new forecast can be considered as a short-range forecast. Therefore, under the present system, scheduled short-range forecasts are available, at a maximum, only three times each day and cover only 12 of the 24 hours.

1.3.2 Air Weather Service

An interesting approach to cope with the need for more frequent short-range forecasts has been taken by the AWS. Beginning with a limited number of bases in the fall of 1971, AWS gradually reorganized terminal forecast responsibilities for all of its 105 conterminous U.S. bases. Now, the local base prepares a 4-hour forecast every two hours, but the forecast for the remainder of the period, out to 24 hours, is prepared every 6 hours by the Global Weather Central (GWC) at Offutt AFB, Nebraska. This arrangement allows each base weather station to focus its attention on the short-range portion of the terminal forecast and provides for a new forecast at a maximum interval of two hours. The two segments of the terminal forecast are combined and issued by GWC. AWS terminal forecasts are required to include details about: cloud heights and amounts, visibility, "weather," surface wind, icing and turbulence (if expected), and the lowest altimeter setting expected during each period into which the forecast is divided with respect to weather changes.

The overall operations of the AWS are significant to civilian short-range weather needs: surface airways observations are taken at more than 100 locations and PIREPS from military aircraft are collected and disseminated. This information is used primarily by military forecasters, but a sizeable amount is also available to civilian aviation interests. Forecast products of the AWS, as shown in Table 1.2, are intended for use by military pilots and controllers. Terminal forecasts and significant weather advisories of terminal conditions are available

for civilian use, but computer flight plans and special mission forecasts, which are prepared for specific military operations, are not. On the other hand, forecast products of the NWS are extensively used by military pilots, particularly In-Flight Advisories which serve common needs for all pilots.

1.3.3 Naval Weather Service

The Naval Weather Service aviation operations are of comparatively minor interest to general short-range weather needs, but do have some impact. Surface airways observations are made at about 50 installations, concentrated mostly near coastal areas, and terminal forecasts are prepared for the majority of those installations. Aside from forecasts tailored to special Navy missions, aviation weather information in the Navy's system is available to civilian interests. Terminal forecasts are similar in style and content to those of the NWS.

1.3.4 Commercial Airlines

Commercial airline operations are of major importance to the aviation community. The detail and volume of weather information required by the airlines has made it necessary and economical for the larger to establish their own weather offices. Some prepare original forecasts of various weather phenomena for both terminal and enroute requirements; most adapt or modify basic NWS products. In either case, the output information is tailored to the specific needs of individual flight operations and in this respect is similar to the military approach.

The airlines derive their economic benefits from their ability to make rapid decisions about route and schedule problems with respect to adverse weather, and from their improvement of winds/temperatures aloft forecasts which in turn are used to select routes and flight levels for minimum fuel consumption. To make the most efficient use of short-range weather information, the airlines have, in many cases, taken full advantage of modern communications and computer technology. In addition, in-flight weather reports from commercial pilots represent a valuable source of short-range weather information which is used extensively in the airlines' operations.

1.3.5 Private Firms

Private meteorological firms serve small commercial carriers and commercial pilots whose weather needs are not satisfied by the present NWS forecast system. These kinds of users contract with private meteorologists who prepare tailored forecasts and computer flight plans.

1.3.6 Short Range Forecast Techniques

Although different sources of short-range aviation weather information exist and various kinds of products are used for short-range aviation weather needs, the approaches, techniques, and procedures used to prepare short-range aviation weather forecasts are fairly standard.

In the most basic breakdown, they are either subjective or objective, and various subtypes can be grouped under the two basic types. Table 1.3 is a list of the general techniques which are commonly used to prepare short-range aviation weather forecasts.

Most aviation weather forecasters employ some combination of subjective and objective techniques to arrive at the final product. However, for short-range forecasts, subjective techniques are used more frequently and a variety of methods have been developed. An excellent description of the various methods in use can be found in a summary of short-range forecasting techniques by Restivo (1971).

1.3.6.1 Subjective Techniques

Extrapolation is probably the most widely used of all subjective methods. Most simply stated, it is the forecasting of a weather pattern or patterns based solely on the past motions of the pattern(s). Its advantages are that it deals directly with the phenomenon to be forecast (e.g., ceiling/visibility, precipitation), and does not require knowledge of the physical processes involved in the formation of the phenomenon. The chief weaknesses and major reasons for forecast "busts" arise from initial analysis errors, timing errors because of acceleration/deceleration effects, and changes in the characteristics of the phenomenon. It gives the best results when the phenomenon to be forecast is well defined, in terms of available data and past history, and the forecast projection is short. Three hours is probably the upper limit of its effectiveness.

Frequently, extrapolation techniques are used to make forecasts of synoptic features, such as fronts, troughs, ..., etc., which can then be related to sensible weather features. This method is known as association, it can also be considered as a form of synoptic climatology. It is superior to the simple extrapolation of sensible weather fields when the particular synoptic feature in question is easier to analyze and possess a more reliable history. In addition, the association of certain sensible weather phenomena with particular synoptic features in a given region or at a specific terminal can be an effective method for experienced forecasters. The drawbacks of the approach are virtually identical to those for ordinary extrapolation.

Table 1.3. General techniques used to prepare short-range aviation weather forecasts.

Subjective Techniques	Objective Techniques
Extrapolation	Persistence
Association	Conditional climatology
(1) Synoptic features	Empirically-derived relationships
(2) Diurnal changes	Map typing
Trend	
Nowcasting	

A basic requisite for both extrapolation and synoptic association is a series of detailed analyses with continuity in a time frame commensurate with the projection of the forecast. For short-range forecasts, data from a relatively dense network of terminals help to resolve details of weather features. Rapid availability of the analyses is also an inherent requirement. The data from surface airways observations are often supplemented by radar data and pilot reports, when available.

Another type of association is based on weather events which occur as a result of diurnal changes. Examples are the formation of radiation fog, the dissipation of convective cloudiness, etc. Application of the technique requires a knowledge of the physical processes responsible for the event and a determination of the likelihood of their occurrence; local climatology is also an important consideration. This technique fails most often because of the complex nature of atmospheric processes and the meteorologist's inability to forecast them with the required degree of precision.

Forecast methods which are based on trend usually involve the graphical depiction of meteorological parameters with time at the forecast terminal and selected "upstream" terminals in the area from which a weather pattern is approaching. The plotted parameters can be those of direct aviation interest, such as ceiling, visibility, etc., or of related interest, such as temperature, dewpoint, temperature-spread, pressure, ..., etc. The procedure is to relate the trend(s) of the parameters at the upstream terminals to those at the forecast terminal in such a manner that significant weather changes can be anticipated. It works best when the changes are uniform and consistent. It is least effective under conditions of development or decay, or with irregularly moving systems.

Nowcasting is nothing more than a description of existing conditions or a diagnosis of a given situation which can be used as a forecast to make operational decisions. In its usual application, it is the method by which, for example, pilot reports of turbulence, icing, or upper level winds are used to advise subsequent flights. It sometimes is the only recourse available to a forecaster when an unexpected weather change occurs and the reasons are not well understood. Examples are the sudden development of thunderstorms in a terminal area where none were expected, or the beginning of heavy snow when rain, or no precipitation at all, was anticipated. In situations like those, rapid communications between the forecaster and aviation interests is a vital necessity. It allows the forecaster immediately to advise pilots and controllers of the existing conditions and provide an estimate of expectations. When subsequent additional data yield a better understanding of the meteorological situation, an updated forecast can be prepared.

1.3.6.2 Objective Techniques

In an examination of the objective techniques used for short-range aviation forecasts, evidence can be found (e.g., Johannessen, 1969) which indicates that persistence, i.e., a forecast of "no change"

from existing conditions, can be a powerful tool for projections of two hours or less. Many subjective techniques are hard-pressed to demonstrate skill against persistence forecasts, and almost no objective techniques are successful in bettering persistence for very short time projections. When viewed on an individual case basis, many examples can be cited where a persistence forecast was inferior to a forecast prepared with some other method, but comparative verifications of forecasts made with different methods, for relatively large samples, will almost always illustrate the relative skill of persistence.

One particular objective technique which can frequently be used advantageously to beat a simple persistence forecast is conditional climatology. While many different forms of forecast aids based on conditional climatology can be found, all are based on the same approach. Given some initial set of conditions, such as ceiling or visibility category, time of day, season, etc., the probability of occurrence of each of several ceiling or visibility categories at some later hour(s) can be estimated. An extensive record of observations (ten years is generally a minimum requirement) is needed to provide a representative and stable data base for the statistical manipulations which are employed to arrive at the final form of the aid. The data base can be processed into a set of look-up tables or can be subjected to statistical screening processes so that the final form is a set of multiple linear regression equations. The tables which have been used at AWS weather offices for many years are an example of the former type. The latter technique is exemplified by the work of Allen (1970) and Crisci and Lewis (1973). The equations derived in the referenced works require initial data for only the forecast terminal. This technique was preceded by one which also requires data from surrounding terminals to yield forecasts for a given terminal. An example of the multi-station approach can be found in Enger et al. (1964).

When an adequate data base is not available for a terminal, aids based on conditional climatology are usually not developed. Even when minimum data base requirements are met, a basic weakness of conditional climatology is often a relatively low frequency of the lowest categories of ceiling and visibility in the sample. At most terminals, those categories are comparatively rare events and forecasts based on limited statistics can be unreliable.

Empirically-derived relationships are those which have been developed with "classical" statistical methods, generally at the local level, for application at a specific terminal only. They are based on some observed relationship between the values of key parameters at an initial time and the onset of some weather phenomenon at a later hour. In many types, the form of the forecast is a simple "yes-no" determination of the event's occurrence. Examples are forecasts of morning radiation fog based on temperature-dew point spreads at sunset, the arrival of off-shore stratus clouds based on initial wind conditions, etc. Sometimes the form of the method requires a forecast of a key parameter for

the time in question for determination of the final forecast. In either case, this type of forecast technique is reasonably good for general guidance but rarely provides the degree of refinement or reliability to be used as is.

Map-typing is a modification of the use of analogues for forecasting. In its general application, a current analysis is matched to a group of maps from past history which bear similar characteristics; the climatology pertaining to the particular map type is then used to make a forecast. In a variation of this technique, the current map type is used to select a particular set of conditional climatology tables which are further stratified by initial conditions. For short-range forecasts, the method has shortcomings because of the generalities inherent in the grouping procedure.

The use of numerical weather models to directly predict aviation weather phenomena has not been included in Table 1.3 because those which are currently operational are either too general with respect to the detail required for aviation purposes, or have time lags such that the normal deterioration of forecast data with time renders them of little use when the forecast data are received, or both. Forecasts from numerical models can be used in a general way to predict the approximate locations of synoptic-scale features which can then be used as a starting point for the more commonly used short-range techniques. An example of this approach is the manner in which NWS upper winds/temperatures forecasts are used. The forecast is a completely objective product which is derived from the NMC Primitive Equation (PE) Hemispheric Model. When the forecast reaches the user, it is based on data which are already six hours old and becomes valid for verification purposes six hours later. However, it is intended for use immediately upon receipt through the following nine hours. In this respect, it has short-range application. However, later upper-level data from pilot reports are often available by the time the forecast arrives and can be used to update the forecast immediately. The forecast then becomes more of a short-range product but the forecast technique used is essentially nowcasting.

A forecast technique which employs data from numerical models, in conjunction with multiple linear regression and other statistical methods, has been developed by the Techniques Development Laboratory (TDL) of the NWS. The technique is called Model Output Statistics (MOS) (Glahn and Lowry, 1972) and is currently used to provide routine automated guidance forecasts of several aviation-related weather elements. While the approach yields reasonably accurate forecasts for projections greater than 12 hours, it has serious shortcomings, in its present form, for short-range use.

1.3.7 Summary

The present "system" for providing short-range weather forecasts to the aviation community is composed of five separate but interdependent systems which generate a number of different products. Only a minority of those products meet the criteria for short-range forecasts as defined at the outset of this document. They are produced by techniques which

are predominantly subjective and which have not changed materially during the last 20 to 30 years. The most common method of communicating short-range weather information is by long-line teletypewriter--a slow and/or inefficient means. Next in order are the telephone and radio, although in many cases the weather information must first travel on teletype circuits to reach the point at which it is then transmitted by those means. Weather offices of some of the major airlines now use modern computer-to-computer communication links and have greatly increased their ability to quickly advise pilots of changing weather conditions.

1.4 The Requirements of a New System

Ideally, the complete and final requirements of a new short-range aviation weather forecast system are to satisfy fully all the needs discussed in section 1.2, in terms of specific phenomena and the measures of effectiveness. However, it was stated earlier that one of the purposed of this report is to propose action to accomplish those objectives which appear realistic and feasible. Therefore, the goals must be more modest.

There are a number of requirements which can be placed on a proposed new system that appear to be well within the realm of reality. First, much better use must be made of modern communications and computer technology. This should apply to the manner in which the various meteorological data reach the aviation forecaster and to the way that short-range weather information reaches the users. Second, the availability must be increased and more efficient use must be made of data which are now in the present system but are under-utilized. Third, the procedures under which short-range forecasts are made must be improved, and the forecaster should be provided with new techniques and aids. Finally, changes to the present system must take into account all related activities and efforts, underway or pending, which will impact on aviation operations. With respect to the last requirement, proposed changes to the present system must fully take into account the current FAA program to modernize its FSS operations and to develop a Pilot Self-Briefing Terminal (PSBT), and the NWS program on the Automation of Field Operations and Services (AFOS).

2.0 Short-Range Forecast Program

In this section, the developmental effort required for the improvement of short-range aviation weather forecasts is discussed. The section has been divided into two sub-sections:

(1) Proposals and recommendations for overall improvement in the short-range forecast system;

(2) Proposals and recommendations for improved forecasts of specific aviation weather phenomena.

Both sub-sections set forth what appear to be the most feasible approaches to meet the requirements stipulated in section 1.4.

2.1 Proposals and Recommendations for Overall Improvement in the Short-Range Forecast System

2.1.1 Communications

From the standpoint of the need for better use of modern communications and computer technology, the implementation of the NWS Automation of Field Operations and Services (AFOS) program will clearly meet the requirement. Communication of weather data will be accomplished on the National Digital Circuit in terms of seconds rather than minutes, data will be stored and displayed much more efficiently than at present, and the availability of AFOS minicomputer systems will permit local computer operations that are now virtually impossible at most weather offices. The potential benefits to the short-range aviation weather forecast system are enormous but can be realized only if full advantage is taken of the AFOS system's capabilities. The majority of the proposals and recommendations in this section are based on those capabilities.

The revolutionary change in communications that AFOS will bring can be a boon to aviation users as well as to the forecaster. Ultimately, AFOS systems will be installed at each of our National Centers and all WSFO's. The system will permit users directly to access weather information on high-speed digital communication circuits. Such an arrangement will allow for rapid updating of forecasts and insure that the "freshest" product is always available in the system. For example, displays of weather information for the use of air traffic controllers could be "driven" and maintained in a current state directly by a WSFO AFOS system. As the weather information is updated by the forecaster at the WSFO, it automatically and instantly would replace the previous information in the controller's display system. Another application of this capability is foreseen with respect to the FAA PSBT program. PSBT's will be driven by a modernized FSS "Hub" which will maintain a weather information base for the user's requirements. The FSS Hub will be serviced by an FAA Aviation Weather Processor (AWP). If the WSFO is linked directly with the AWP, weather information that gets updated by the forecaster will automatically and instantly replace the outdated information in the Hub base and PSBT users will always receive the latest information.

An important aspect of the proposed WSFO-AWP link is the possibility of allowing the aviation forecaster to use the capability of the AWP computer system. The AFOS minicomputer system may not be able to fully serve all the computational needs of the forecaster because of its size and the other requirements it must fulfill. Therefore, certain forecast techniques may not be implementable at the WSFO level but could be run on an AWP. The feasibility of establishing such an arrangement should be fully explored.

2.1.2 Forecast System

A major proposal in this document calls for reorganizing the structure and format of the present NWS Domestic aviation forecast program. Each WSFO with aviation forecast responsibilities would issue its terminal forecasts for a 0-6 h period at either 2, 3, or 4 h intervals, while forecasts for a 7-24 h period would be issued at either a 4 or 6 h interval. The short-range terminal forecasts would be designed for operational decision making and would contain in a fixed format, forecasts of ceiling, visibility, weather, obstruction to vision, and surface wind. The longer-range forecasts would be intended for flight planning purposes and would consist of forecasts of the same elements listed above for the operation decision making, except that these would be objective in nature. The role of the meteorologists in the WSFO's would be to insure that there is continuity between the decision and flight planning portions of the terminal forecasts. The short-range forecasts would be continuously monitored and updated whenever necessary, in accordance with established amendment criteria. The monitor/update procedure can be largely automated in the AFOS system. Since, both the surface observations and terminals would contain a fixed format, the AFOS minicomputer would compare each observation of ceiling, visibility, weather and wind with the official forecast to determine if a discrepancy exists. If so, the system will advise the forecaster with a message which contains objective guidance forecasts to help on the preparation of a revised terminal forecast. An experiment with such a procedure for terminal forecasts will be conducted by the NWS at the AFOS Experimental Facility in the near future (Lowry et al., 1974).

In place of the current area and route forecasts an Aviation Route Forecast (ARF) would be prepared. This system would require the forecaster to predict specific variables at individual grid points in a coded format on the AFOS system. This data would then be transmitted to the FAA's Aviation Weather Processor, which would then prepare a forecast for any route in the country. With the implementation of the standardized PIREP format, computer programs could be developed to monitor the automated route forecast in a method similar to that established for our terminal forecast program. A series of new ARF arrays would be produced every 4 hours and would be valid for the next 8 hours. The forecast package would be broken down into 1-, 2-, and 4-h time periods. The old data would be removed from the system every 2 hours. Each stored entry array would then be transmitted and stored in the FAA's AWP. The arrays of data would then be integrated into route forecasts. Software programs would then scrutinize these arrays and produce a route forecast for any two points in the country.

Also by forecasting specific variables at individual grid points, computer generated graphics could be developed for each of the following forecast variables:

1. Cloud cover
2. Bases
3. Tops
4. In flight visibility
5. Weather and obstruction to vision
6. Convective activity
7 Freezing level
8. Icing
9. Turbulence
10. Height at which turbulence is encountered.

The winds aloft program would be capable of providing a wind and temperature for any level or location in the conterminous U.S. Once again, monitoring and updating programs utilizing PIREPS, etc. could help us to update these forecasts more efficiently. The inflight advisory program will become more standardized, along with centralizing the production of the advisories at one location, most likely the National Severe Storms Forecast Center (NSSFC) in Kansas City.

All these forecasts would continue to be issued in a written form for dissemination to all users, either directly over digital circuits or indirectly by transformation to conventional teletype messages. The standardization of all of the aviation forecast products will allow more efficient handling and will also allow further computer processing and future dissemination breakthroughs, such as voice response system (VRS) technology. Graphical displays of forecast products could also be designed for use by FSS, ARTCC and local tower controllers, on the basis of their specific weather requirements, along with supplementing the PSBT weather base. Products such as forecasts of thunderstorm positions, icing, and turbulence zones, etc., are foreseen for this form of the forecast.

One of the major supporting reasons for proposing the change in the NWS forecast system is evidence that objective forecasts for longer-range projections can be as good or better than subjective forecasts. This has been demonstrated for projections as short as seven hours in a number of comparative verifications conducted by the Techniques Development Laboratory (TDL) (Allen, 1969; Bocchieri et al., 1973; Globokar, 1974). By freeing the WSFO forecaster from the responsibility for the longer-range forecasts, his attention could then be concentrated on the short-range problems.

2.1.3 Improved Forecast Methods

To help the forecaster prepare improved short-range forecasts, new and better tools will have to be provided. These tools will consist of:

(1) New or improved products and techniques with conventional data.

(2) New products and techniques with new types of data.

An example of (1) is a simple regional plot of hourly surface weather observations which could be provided to the forecaster within a few minutes after each hour by means of the AFOS system. At present, the data for such a plot take ten minutes to arrive at a WSFO, and another ten minutes or more are required to plot the data manually.

Since virtually every aviation forecaster uses some form of a regional plot of observations, a considerable amount of time could be saved by improved communications and automated plotting. Various types of analyses of the plotted data could be done; the choice could be made at the local or individual level.

Another example of (1) would be hourly regional plots of all pilot reports. Again, the data would be presented to the forecaster in short order. This source of data has the potential of providing a large quantity of valuable information to supplement and fill the gaps in our present observation network but up to now has not been used efficiently. It is foreseen that one approach to the use of pilot reports would be to break down each report into specific types of phenomena, such as turbulence, icing, cloud tops, etc. and plot each field individually. The forecaster at the AFOS console could examine each plot separately or overlay several plots, as he choses. The development of the two products described above would be the responsibility of the NWS AFOS group involved with new products.

An example of a forecast method proposed for development involves use of radar data for short range aviation weather forecasts. Two parallel lines of attack would be required. One would be the development of a computerized, objective prediction technique for the movement of radar-observed echoes. The aim would be to process radar data in digitized form together with other associated meteorological information to determine the position of these echoes a short time ahead in the future. Initial efforts in this area are described by Alaka et al., 1975, Meunch and Lankin, 1976; and Alaka et al., 1977.

The other would be the determination of relationships, if any, between echo characteristics and such aviation weather phenomena as cloud heights, visibility, winds, precipitation, thunderstorms, icing, and convective turbulence. Results of the two investigations would be merged into an overall forecast method which would produce specific short-range aviation forecasts. The development work would also require determination of a suitable mode for transmitting and presenting the products to the users.

Meteorological satellites can provide data on a scale required for aviation forecasts. For example, Geostationary Operational Environmental satellites (GOES) currently provide meteorological data at a frequency of 30 minutes. The National Environmental Satellite Service (NESS) has launched several synchronous meteorological satellites and GOES data are being provided to all WSFO's for operational use.

To take full advantage of GOES potential capability to provide significant guidance for short range aviation forecasts, a development effort should be initiated. The objective of the effort would be to determine the feasibility of using GOES data for short-range forecasts of terminal and enroute weather elements such as clouds, visibility, winds, thunderstorms, and turbulence. It would be necessary to establish relationships between satellite-observed data and aviation weather elements, and develop techniques to forecast the features. Because of the nature of satellite data, early technique development will likely be largely subjective, but objective techniques will eventually be formulated. Efforts to develop objective techniques with geosynchronous satellite data were described by Sikula and Vonder Haar (1972). Data available for analysis from these satellites are described in the GOES/SMS User's Guide (1976).

2.1.4 Instrumentation

In addition to the "new" type of data which meteorological satellites can furnish for aviation weather applications, different forms of data are now being introduced for aviation purposes as a result of the development of a number of new instruments during the last several years. In some cases, the manner in which aviation weather elements are observed by these new instruments represents a different concept of the element, and new forecast techniques must be developed accordingly. For example, the need for automated visibility observations has led to the development of instruments which define visibility in different terms than the traditional prevailing visibility observation. Both George and Lefkowitz (1972) and Hochreiter (1972) have presented a general examination of the new concepts involved, the types of instruments that have been developed, and the possible future direction. Efforts to develop new observation techniques of visibility have included recent developments in slant-range visibility measurement (Collins et al., 1972; Wheelock et al., 1972; Bradley et al., 1976; McManus et al., 1976). A report by Ingrao (1976) provides cost information on visibility equipment that could form a basis for future upgrading and/or deployment of visibility measurement equipment.

Instrumentation for the detection and measurement of cloud conditions from the ground has also been under development. The objective is to devise an automated system with greater accuracy than conventional ceilometers. The use of lidar and infrared devices are being explored and the type of data presented to the aviation forecaster will likely have different characteristics from present forms.

Other types of instruments which are being developed for aviation purposes are the Alert System for terminal area low-level wind shear, and laser Doppler systems for wind, turbulence, and wake vortex detection and tracking. Also, new methods to automatically receive winds and temperatures from commercial airliners are being tested. Airborne weather measurements telemetered to the forecast offices would be of immediate aid in the improvement of short-range forecasts. It is desirable to adapt and test

recently developed airborne observation equipment and systems for automatically providing winds, temperature, turbulence and icing information for this purpose. Airborne weather measurements telemetered to the forecast offices would be of immediate aid in the improvement of short-range forecasts. It is desirable to adapt and test recently developed automatic airborne observation equipment and systems which provide winds, temperature, turbulence and icing information for this purpose.

In short, development over a wide range has been underway during the last several years, which will soon present short-range aviation weather forecasters and users with new forms of information. In some cases the information will supplement present data. In others, it will represent a new approach to the measurement of weather elements. New forecast techniques will be required in either case, and the potential for better forecasts can be realized by the proper utilization of the new improved data.

2.1.5 Mesoscale Observational Networks

Along with the development of automated instrumentation or aviation weather observation has come experimentation with automated observation systems surrounding a terminal on a scale and density commensurate with short-range aviation weather requirements. Since short-range terminal weather is a mesoscale forecast problem and since the conventional synoptic observation network is inadequate for mesoscale purposes, considerable interest remains in the potential benefits to be derived from mesonets.

Two experiments utilizing mesonets for aviation weather forecasting have been conducted in recent years. One was at the FAA's National Aviation Facilities Experimental Center (NAFEC) at Atlantic City (Entrekin et al., 1968). The objective of this experiment was to utilize a mesometeorological network (mesonet) for the improvement of quantitative short-range terminal weather information. For 15-60 minute forecasts of cloud base height, RVR, and wind, comparisons were made of objective techniques which used mesonet data, subjective techniques which did and did not use mesonet data, and control forecasts based on persistence and the climatological expectancy of persistence. In general, none of the techniques which used mesonet data produced forecasts significantly better than persistence. However, three weather situations were identified where the use of a combination of mesonet and radar data produced forecasts significantly better than persistence. These situations occurred when: 1) RVR was being restricted by snow, 2) dense fog was being accreted by rain, and 3) wind shift lines could be identified by radar or surface wind reports. It could be said that the experiment at least demonstrated the potential for mesonet data applications toward aviation weather problems.

More recently, a mesonet experiment, initiated in 1972 (Hering et al., 1972), has been completed at the Air Force Geophysical Laboratory facilities in Bedford, Massachusetts. The objectives of this mesonet experiment were essentially identical to those of the earlier NAFEC experiment, i.e., to develop and demonstrate new methods to deal with short-range forecasting problems and, in particular, to evaluate the relationships between the density and types of observations and the accuracy of terminal weather forecasts. Two reports, one by Tahnk, 1975, and the other by Chisholm, 1976, describe efforts to develop improved forecasts of visibility up to one hour. The results, based on the analysis of approximately two years of fog forecasting data, showed that improvements in aviation forecasts achieved through the use of mesonetwork observations were at best marginal.

The advent of: 1) improved three dimensional observations (e.g. satellites, surface observations, radar) on a continuous basis, 2) improved atmospheric forecast models (e.g., boundary layer models) that require detailed observations, and 3) modern data processing, portends the potential for significantly improving the forecasts of terminal aviation weather. However, before committing large sums of money to a mesometeorological network, an analysis is warranted to determine what combination of instruments, atmospheric forecast models, and data processing, will provide significant terminal forecast improvements in 0-2 hour time periods. Also, an estimate of the cost involved would be highly desirable.

2.1.6 Numerical Models

Perhaps the near-ultimate product to satisfy the needs of the aviation weather forecaster would be highly accurate short-range numerical forecasts of temperature, moisture, and wind with sufficient variability in time and space to meet user requirements. The three forecast elements could be used directly or indirectly for all types of aviation forecasts. The attainment of such a technique, however, is not anticipated in the foreseeable future. While efforts are being directed toward the development of smaller-scale numerical models--TDL's boundary layer model and NMC's hurricane model are examples--formidable problems will continue to exist for the next several years with respect to the development of an operational mesoscale model. In addition to uncertainties about the mathematics and physics involved, the major obstacles are a lack of observations with sufficient horizontal and vertical resolution and computers with the power and speed to meet operational requirements. The Panel on Short-Range Prediction of the National Academy of Sciences (1977) recommends that NOAA study the potential benefits of providing greater computing power to NMC for a further increase in LFM resolution.

McGovern (1974), discussing the prospects for dealing with mesoscale problems relative to anticipated advances in observational and computer technology, estimated that mesoscale forecasting capability could be developed by the mid 1980's. Ramage (1978), on the other hand, states that modest improvements might stem only from forecast services which respond to local conditions and priorities, and which emphasize early

detection and warning. Adaptation of the present synoptic observation and numerical prediction system for mesoscale forecasting purposes will be investigated by various researchers. Using such approaches as the "window" or "telescoping" grid method (e.g., Kaplan et al., 1974) and the "nested" or grid method (e.g., Perkey et al., 1974), improvement in the specification of smaller-scale weather features is expected. The application of these approaches to short-range aviation weather forecast problems remains to be seen. USAF will undoubtedly investigate aviation applications for its "window" mesoscale approach during the next few years; NWS will probably do likewise when TDL's boundary layer model becomes operational in the near future.

2.2 Proposals and Recommendations for Improved Forecasts of Specific Aviation Weather Phenomena

2.2.1 Terminal Weather Phenomena

2.2.1.1 Cloud Heights/Amounts

A number of proposals were discussed in section 2.1 which would provide help for the cloud heights (base and tops)/amounts short-range forecast problem; hourly AFOS system plots of surface observations and pilot reports, development of an objective cloud advection technique, improved use of radar and satellite data. Details about these approaches can be found in that section. In addition, certain statistical forecast techniques are also recommended for consideration in this plan. One is the single-station (SINGSTAS) multiple linear regression equation method (e.g., Crisci and Lewis, 1973), another is the occurrence/reoccurrence profile method developed by Martin (1972). Both techniques are sophisticated forms of conditional climatology and share the advantages and disadvantages of that approach. The positive aspects of conditional climatology are that forecasts require only local observations for input and they can be generated at any time with minimal computer effort. The major disadvantages are that the method employs no predictive information and generally requires a substantial data base, although Martin has been experimenting with modeling procedures to circumvent the latter problem. Martin's work deals exclusively with 2- and 4-h projections, while the SINGSTAS development work has generally involved longer projections, three or four hours having been the shortest with subsequent projections out to 16 hours. At the present time, however, TDL is preparing an experiment for the AFOS Model Facility which will use single-station equations with projections of 1, 2, 3, 4, and 6 hours, to generate ceiling forecasts (Lowry et al., 1974). It is proposed that a comparative verification be conducted between the two conditional climatology techniques for a common terminal or terminals. The results should be used to determine the form of conditional climatology to be used in the short-range forecast system. The test should be a joint TDL-AWS effort.

Statistical forecast techniques which use predictive data for input, specifically output from numerical models, have generally not been used for short-range forecasts. The reasoning has been that the time lag

involved in using numerical data is too great for operational use; and this reasoning, for the most part, has proven valid. However, in a comparison conducted by Bocchieri et al., (1973) between (1) a forecast technique which used the Model Output Statistics (MOS) method (Glahn and Lowry, 1972), (2) a single-station conditional climatology technique, and (3) a hybrid technique which combined (1) and (2), the hybrid technique verified best, overall, for projections of four hours, the shortest used in the study. The conclusion would seem to be that the numerical data contributed importantly in the predictive sense, while the conditional climatology added critical information about local effects. It is recommended that additional investigation be made of forecast tehcniques which combine numerical predictive data with conditional climatology, specifically for projections of 1 to 6 hours from observed data time. The work could begin following determination of the best conditional climatology method to use, as proposed earlier, and should be expanded from its original form to treat predictors from additional numerical models in operational use.

2.2.1.2 Visibility

With the exception of the objective cloud advection technique, all of the proposals discussed in section 2.2.1.1, with respect to cloud heights/amounts, apply as well to the visibility forecast problem. Conditional climatology is probably more important to visibility forecasting than to ceiling forecasting since local effects usually have less bearing on the latter element. It could be argued that greater emphasis should be placed on improving visibility forecasts since it has become the crucial weather element in determining permissible aviation operations at major airports. It is also important that work be initiated to develop techniques for forecasting RVR and SVR when the observing technology becomes standardized.

2.2.1.3 Surface Wind

The proposed hourly AFOS system plots of surface observations will be highly applicable to the short-range wind forecast problem. The use of radar, satellite and certain types of mesonet data will also be relevant to the surface wind forecast problem, particularly with respect to predicting wind shifts. Thus, some of the previously described proposals in section 2.1 will have specific applications for this phenomenon.

The approaches mentioned above will involve mostly subjective techniques for surface wind forecasts. An objective technique which is proposed for development in this plan is the use of MOS in combination with a suitable high resolution operational numerical prediction model, particularly one which produced superior forecasts of sea-level pressure (SLP). The reason is that the sea-level pressure gradient is a determining factor in the surface wind; therefore better SLP distribution forecasts should presumably lead to better wind forecasts. In the development of the technique, potential predictors from the other models should also be screened because the wind is influenced by other factors which may be better handled by these models. For the approach to be meaningful, the forecasts will have to be issued, say, at 2-h intervals, with projections of 2, 4, and 6 hours.

2.2.1.4 Low-Level Wind Shear

Although a data base for the development of timely accurate forecast techniques has not been developed, forecasts are being tested utilizing relationships presented by Sowa (1974) and those developed in the United Kingdom. A test of the Sowa technique was conducted during the 1976-1977 winter season for seven east coast airports. The results of this test and the evaluation of other techniques have not yet been published, but it is anticipated that as a result of the tests, guidelines will be made available to the WSFO's for improved forecasts of wind shear.

The vertical resolution required for wind forecasts in the lowest levels of the atmosphere appears beyond the capability of current operational models. Thus, the near-time introduction of forecast techniques will depend, to a large extent on new detection systems, such as the Low-Level Wind Shear Advisory Systems (LLWSAS), and on empirical-physical relationships.

2.2.1.5 Conditions Affecting Wake Vortices

A conceptual approach to wake vortex avoidance has been developed (Wilson et al., 1972) which considers both the detection and prediction of wake vortices and proposes an optimum system to combine the two capabilities. Development and testing of appropriate detection devices and a numerical prediction model (Brashears and Hallock, 1973 and Hallock and Wood, 1976) are being conducted by the Department of Transportation's Transportation Systems Center (TSC). From the prediction standpoint, highly accurate forecasts of wind, wind shear and stability in the lowest 2500 feet of the atmosphere would be required as input to the wake vortex transport model. The likelihood of achieving such a forecast capability rests with the development of a small-scale atmospheric model. However, in lieu of a forecast, wind observations are currently incorporated into a vortex avoidance system (VAS). The installation of wind sensors for use in determining vortex movement at Chicago O'Hare Airport has been completed and the VAS will undergo operational evaluation for a 5-month period beginning June 1978. In this test the winds measured at the 50-foot level in the approach zone will be the basis for determining when the vortices are not a hazard to following aircraft. A sophistication beyond the VAS would be to have an active ground-based tracking system which determines when the approach departure corridors are free of vortices.

2.2.1.6 Turbulence

As discussed in section 1.2, the two types of turbulence that are of concern to terminal operations are mechanical and convective. For both types, the most commonly used forecasts are obtained by association with synoptic features, combined with nowcasting. Therefore, immediate aids to forecasters will be the hourly AFOS system plots of surface observations and pilot reports; improved use of radar data will also provide help for better forecasts of convective turbulence. Beyond that, further improvement of short-range forecasts will depend on both

improved observations and small-scale numerical model developments. For mechanical turbulence forecasts, more accurate specification of winds and temperatures in the atmospheric boundary layer is required.

Short-range forecasts of turbulence should improve when the accuracy and timeliness of boundary layer forecasts eventually fulfill the operational requirements. In particular, short-range forecasts of convective turbulence should show significant improvement when stability and moisture conditions can be forecast more accurately in the lower levels of the atmosphere by numerical models. Therefore, the recommended monitoring of numerical model development by the NWS Aviation Forecast Task Group should also be directed towards improving turbulence forecasts. In addition, the group should maintain awareness of the work being done by the National Severe Storms Laboratory (NSSL) to better define turbulence zones in thunderstorms. The results of the NSSL studies could be used to skirt thunderstorms or penetrate selected portions thereof rather than avoid thunderstorms by large distances.

2.2.1.7 Thunderstorms

With respect to the proposals discussed in section 2.1, the improved use of radar data and the use of GOES data are more relevant to the thunderstorm forecast problem than the others, although the hourly AFOS system data plots will also have applicability. Generally, these forecast aids will be most useful when thunderstorm activity has already developed and is in progress, as opposed to forecasts of initial outbreaks. For the latter aspect of the problem, marked improvement over present forecast techniques must await the advent of the sophisticated boundary layer models previously discussed. For the former aspect, improvement in present capabilities will be provided by radar processing techniques such as those discussed by Charba (1974), Meunch and Lankin (1976), and Alaka et al., (1977) thus, the integration of pertinent meteorological information into the radar processing techniques can be expected to improve the 0-2 hour forecasts of thunderstorms. Another possibility for significant improvement in short-range forecasting of thunderstorm development would be the application of a new system for measuring temperatures in the lower atmosphere called the Radio Acoustic Sounding System (RASS) (North et al., 1973). RASS has the capability of providing continuous temperature profile monitoring up to an average level of 1 km and could thus provide information useful to forecast the onset of convective development. As Doppler radar, laser, acoustic, and other new systems become available, an attempt should be made to utilize them for improving forecasts of thunderstorms and their associated hazards. Other recommendations for dealing with the short-range thunderstorm forecast problem involve the proposals stated in section 2.1.

2.2.1.8 Significant Precipitation

As discussed in section 1.2, precipitation of significance for aviation operations comprises freezing rain, sleet, snow, heavy rain, and hail. Forecast techniques for the first three varieties in the list share a common approach: following a determination of precipitation, a prediction is made of the temperature structure of the middle and lower troposphere by direct or indirect means. Surface and boundary-layer temperature forecasts are especially critical. Present medium-range forecast techniques which employ output from numerical models (e.g., Bocchieri and Glahn, 1972) do reasonably well in differentiating liquid and frozen precipitation for relatively large areas but lack the resolution required for short-range localized forecasts. For the latter problem, the methods usually employed are extrapolation, now-casting and use of radar. Therefore, the proposed hourly AFOS system plots of surface observations and pilot reports, and the improved use of radar data, will have immediate application. The longer-term solution to the problem will require precise temperature forecasts by numerical models; observation systems such as RASS may also eventually provide information for short-range forecast applications.

Heavy rain and hail forecasting also impose common needs, ie., a prediction of moisture and stability characteristics through a considerable vertical extent of the atmosphere and a determination of the intensity of anticipated convective activity. Since heavy rain and hail are usually associated with thunderstorms, the recommendations and proposals stated in section 2.2.1.7 also apply here and will not be repeated. However, amplification of basic thunderstorm forecasting techniques will be required for specific application to the heavy rain and hail problem.

2.2.1.9 Icing

Aircraft, especially helicopters, require accurate forecasts of icing conditions which will include air temperature, liquid water content and drop size distribution in clouds, as well as type of icing. Knowledge of the parameters will depend on establishing their relationships to the types, formation and location of the clouds. An effort to establish these environmental relationships is required. In addition, an automatic airborne weather observation system should be adapted for use on aircraft (helicopters) that will provide the forecaster with information on winds, turbulence, temperature and icing conditions during flights; such information can be processed speedily into accurate short-range forecasts for following aircraft.

2.2.1.10 Surface Temperature

Until the introduction of superior boundary layer numerical models, short-range surface temperature forecasting will most likely continue as at present, by subjective updating of medium-range objective forecasts. A useful tool for updating purposes would be provided by the proposed hourly AFOS system plots of surface observations.

2.2.1.11 Altimeter Setting

Like surface temperature forecasts, short-range altimeter setting forecasts are usually accomplished by updating a previous medium-range forecast--in this case sea-level pressure (SLP)--with hourly surface observations. It follows that the proposed hourly plots of surface observations will be a valuable aid. It is proposed that the superior SLP forecasting ability of LFM be investigated for application to the short-range altimeter setting forecast problem. As was pointed out in section 2.2.1.3, with respect to a similar proposal for surface winds, LFM can be run at short intervals, which would permit frequent updating. The specific manner by which the SLP forecasts would be used for altimeter setting forecasts--either directly or by a MOS technique--should be part of the proposed investigation. All other comments about the proposal made in that section also apply here.

2.2.2 Enroute Weather Phenomena

2.2.2.1 Cloud Layers

The basic problem that arises when one compares techniques and approaches for cloud heights/amounts forecasts with those for cloud layers is that the latter requires observed cloud top data. At present, pilot reports are the best source of cloud top information followed by radar observations and, to a much lesser extent, satellite data. Initially, the proposed hourly AFOS system plots of pilot reports will be the most useful aid that can be provided to the forecaster. The proposed cloud advection technique and the proposal for improved use of radar data have the potential for improving cloud layer forecasts if the pilot report data can be incorporated into the approaches by automated, objective methods. It is recommended that this problem be explored if the proposed technique development, as described in section 2.1, is approved and initiated. Also recommended is consideration of the cloud layer forecast problem as part of the earlier proposal for improved use of satellite data. The longer-range recommendation is that applications to the cloud layer forecast problem be included as part of the NWS Aviation Forecast Task Group's monitoring of numerical model development.

2.2.2.2 Winds/Temperature Aloft

The new system envisioned continues the practice of NMC generating the winds/temperatures aloft guidance. This system would provide the capability of obtaining, via request/reply type procedures, a wind and temperature at any level and location in the conterminous U.S. The WSFO's would monitor these winds and temperatures over their individual areas of responsibility and modify or update them by means of later information, primarily pilot reports utilizing the AFOS system plots of pilot reports. Automated monitoring and updating procedures could eventually be developed at NMC, using winds and temperatures received automatically from special equipment placed in the commercial aircraft fleet. The technique would involve a comparison of the forecast winds

and temperatures, with those later observations received from the airlines and automatically producing an amendment if the winds and temperature are deviating from established amendment criteria. Once this technique is developed the WSFO's would just quality control the product. In addition, it is recommended that the development of techniques with satellite data include the use of wind information derived from cloud motions as observed by GOES. Eventually, more accurate and timely winds/temperatures aloft forecasts will likely result from better numerical model development, but for the next several years the updating procedure described above will probably yield the best forecasts.

2.2.2.3 Turbulence

The discussion in section 2.2.1.6 about turbulence as a terminal weather phenomenon can be equally directed towards turbulence as an enroute phenomenon with respect to the convective and low-level mechanical varieties. The points and recommendations made earlier, therefore, do not need to be repeated. The kind of turbulence that creates the most significant problems for enroute operations is clear air turbulence (CAT). A considerable amount of research has been spent on CAT forecasting techniques and the overall results have been somewhat disappointing. While it is true that skill can be shown for forecasts of relatively large zones where CAT encounters may be expected, verification scores in absolute terms remain low. The basic problem is that CAT is a mesoscale phenomenon, in both time and space, and traditional forecast methods have dealt with synoptic scale atmospheric features (e.g., Endlich and Mancuso, 1965). That CAT is a mesoscale phenomenon has been clearly demonstrated (e.g., Thompson, 1973) and, while recent efforts to use satellite data for a more detailed analysis of atmospheric conditions conducive to CAT have been moderately successful (Woods et al., 1973), the ability to make accurate mesoscale forecasts of the upper troposphere does not appear to be forthcoming in the next decade. The present technique--used by a number of airline meteorology offices--of updating/modifying CAT zone forecasts with the use of pilot reports for short-range forecasts will probably offer the most success for the immediate future. It is recommended that a similar practice be instituted at the WSFO level as part of this plan. In a manner parallel to that proposed for winds/temperature aloft forecasts, the basic CAT zone forecasts would continue to be prepared at NMC for medium ranges and be updated at the WSFC by means of the hourly AFOS system plots of pilot reports. It is further recommended that, for the improvement of the short-range forecast of CAT, satellite data be applied and the utilization of enroute aircraft reports of ozone concentrations and water vapor measurements be explored (Beckwith, 1975).

Perhaps the best solution for the operational problems associated with CAT will be the development of airborne instruments capable of detecting the phenomenon with sufficient lead time for the pilot to take evasive action. Three types of systems--the CO_2 laser Doppler, the microwave radiometer, and infrared radiometer--have been under investigation by the FAA and NASA but none has yet proven acceptable. This aspect of the efforts to deal with the CAT problem is not proposed as part of the development plan.

2.2.2.4 Thunderstorms

The forecast problem for thunderstorm activity en route is essentially the same as in the terminal area. Present forecast techniques in the 1-6 h range are fairly successful in delineating areas susceptible to thunderstorm activity on an operational day-to-day basis. Very short forecasts in the 0-1 h range which pinpoint the location of thunderstorms with precision are under development in TDL. They make extensive use of digitized radar data and show promise for eventual operational use (Alaka et al., 1977).

2.2.2.5 Ozone

Data on ozone concentrations from surface and satellite instrumentation will be made available with regular frequency beginning in 1980. These data, together with other atmospheric parameters, e.g., temperature, wind, atmospheric stability, will form the basis for short-range forecasts of ozone concentrations for use by transport aircraft.

2.2.2.6 Altimeter Setting

The remarks and recommendations made previously about icing and altimeter setting in sections 2.2.1.9 and 2.2.1.11, under terminal weather phenomena, apply with virtually equal weight here and need not be repeated.

2.3 Summary of Proposals

The following is a summary of the proposals presented in detail in sections 2.1 and 2.2 of the development plan:

For Overall Improvement in the Short-Range Forecast System

- Establish an experimental program for short-range aviation forecasting at the AFOS Experimental Facility.
- Develop AFOS system plots for hourly surface airways observations and pilot reports.
- Establish an AFOS-FSS experimental program for processing forecasts.
- Change the structure and format of the present NWS aviation forecast system.
- Develop improved models for forecasting weather for aviation use.
- Develop an improved objective cloud advection technique.
- Develop forecast techniques which make more effective use of radar and satellite data for improved forecasts of thunderstorms, ozone concentrations and enroute winds and temperature.

- o Establish relationships between types and location of clouds with liquid water content, temperature and drop size distribution to improve the forecast of icing conditions.

- o Develop automated airborne weather observation systems for transmission of enroute data to forecast offices for use by forecasters or for integration into the computerized short range forecast technique.

For Improved Forecasts of Specific Aviation Weather Phenomena

- o Develop combined MOS/conditional climatology forecast techniques for ceilings and visibility.

- o Develop MOS techniques with smaller-scale numerical models to forecast icing, CAT, and winds and temperatures aloft.

3.0 Timing

The feasibility of the development plan is strongly dependent on the capabilities of the AFOS system and, to a lesser extent, on the configuration and capabilities of the FAA AWP-FSS Hub-PSBT system. Therefore, the overall schedule of events for implementation of the plan will be tied directly to the implementation schedule for those two systems. The AFOS system implementation has begun with the installation of an Experimental Facility at Silver Spring, Md. This facility has been designed to simulate the operations of a typical WSFO. It is important to note that, AFOS systems will be installed in 1978 at four national NWS centers, including NMC. Only when the NMC AFOS system is fully operational and linked with AFOS systems at all WSFO's can the proposed restructuring of the NWS aviation forecast system become a reality.

4.0 Transition to the New System

Changing to the new system proposed for short-range forecasting will be a stepwise procedure whose progress will be determined by:

(1) the installation of AFOS systems at WSFO sites and NMC.

(2) the design and installation of AWP-Hub FSS-PSBT systems.

(3) the development and implementation of new products and techniques for the aviation forecaster.

As indicated earlier, the proposed restructuring of the NWS aviation forecast system cannot begin until the NMC AFOS system is fully operational and linked with AFOS systems at WSFO's. (Thus, by the end of that year, AFOS systems will have been installed at about 30 WSFO sites.) The first stage of the overall

transition would occur when NMC comes into the system and is linked to these WSFO's with AFOS capability. At that time, each WSFO with aviation responsibility would begin to prepare and issue short-range forecasts while NMC assumes responsibility for the longer-range portions of the forecasts. As each new WSFO then entered the AFOS system network, the same reorganization of aviation forecast responsibilities would take place until all WSFO's were in the system.

At the time of the initial changeover in the aviation forecast system, the form and content of the two portions of aviation forecasts would be determined by "state-of-the-art" conditions. The plan calls for eventual inclusion of all pertinent weather phenomena in aviation forecasts, but at the outset of the transition, only those phenomena for which forecasts would be readily adaptable would be included. The proposed hourly AFOS system plots of surface observations and pilot reports should be available in the early stages; possibly some of the proposed forecast techniques will probably be in the system at that time.

For NAS users without access to AFOS-compatible equipment (this includes the FSS system prior to its transition) the change in the NWS aviation forecast structure will have little or no effect on their ability to receive required information. While teletypewriter communications will be eliminated at the level of the WSFO-NMC, all external users of NWS products will still be able to access that information by means of teletypewriter exactly as at present. Since aviation forecasts will exist in two portions, however, a merging capability will be required within the NWS system so that the total forecast will be available from a single source. The merging function could be performed at either NMC or at the WSFO responsible for the terminals or area in question.

5.0 Conclusions

(1) The present "system" which provides short-range forecasts to the aviation community is inadequate. Short-range forecasts, as such, are seldom available and do not contain all required information, even at those times when they are available as a valid product.

(2) Impending changes in the communications technology of the NWS and the FAA can be used to effect significant improvements in meeting short-range forecast needs. The increased communications capability will allow a restructuring of the NWS aviation forecast system such that short-range aviation forecasting will be a specialized activity.

(3) Significant breakthroughs with respect to improving the accuracy of aviation forecasts will take time to develop; they must await major improvements in small-scale numerical models. Nevertheless, discernible improvements in short-range forecasts could be obtained immediately if more and better use were made of information which is available in the system today.

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